Chapter 30: The Nucleus

Practice Problems

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1. An isotope of oxygen has a mass number of 15. The atomic number of oxygen is 8. How many neutrons are in the nuclei of this isotope?

   $A - Z = 15 - 8 = 7$ neutrons

2. Three isotopes of uranium have mass numbers of 234, 235, and 238 respectively. The atomic number of uranium is 92. How many neutrons are in the nuclei of each of these isotopes?

   $A - Z =$ *neutrons*
   $234 - 92 = 142$ neutrons
   $235 - 92 = 143$ neutrons
   $238 - 92 = 146$ neutrons

3. How many neutrons are in an atom of the mercury isotope $^{200}_{80}\text{Hg}$?

   $A - Z = 200 - 80 = 120$ neutrons

4. Write the symbols for the three isotopes of hydrogen in Figure 30–2 with 0, 1, and 2 neutrons in the nucleus.

   $^{1}_{1}\text{H}$, $^{2}_{1}\text{H}$, $^{3}_{1}\text{H}$

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5. Write the nuclear equation for the transmutation of a radioactive uranium isotope, $^{234}_{92}\text{U}$, into a thorium isotope, $^{230}_{90}\text{Th}$, by the emission of an α particle.

   $^{234}_{92}\text{U} \rightarrow {}^{230}_{90}\text{Th} + {}^{4}_{2}\text{He}$

6. Write the nuclear equation for the transmutation of a radioactive thorium isotope, $^{230}_{90}\text{Th}$, into a radioactive radium isotope, $^{226}_{88}\text{Ra}$, by the emission of an α particle.

   $^{230}_{90}\text{Th} \rightarrow {}^{226}_{88}\text{Ra} + {}^{4}_{2}\text{He}$

Practice Problems

7. Write the nuclear equation for the transmutation of radioactive radium isotope, $^{226}_{88}\text{Ra}$, into a radon isotope, $^{222}_{86}\text{Rn}$, by the emission of an α particle.

   $^{226}_{88}\text{Ra} \rightarrow {}^{222}_{86}\text{Rn} + {}^{4}_{2}\text{He}$

8. A radioactive lead isotope, $^{214}_{82}\text{Pb}$, can change to a radioactive bismuth isotope, $^{214}_{83}\text{Bi}$, by the emission of a β particle and an antineutrino. Write the nuclear equation.

   $^{214}_{82}\text{Pb} \rightarrow {}^{214}_{83}\text{Bi} + {}^{0}_{-1}e + {}^{0}_{0}\overline{\nu}$

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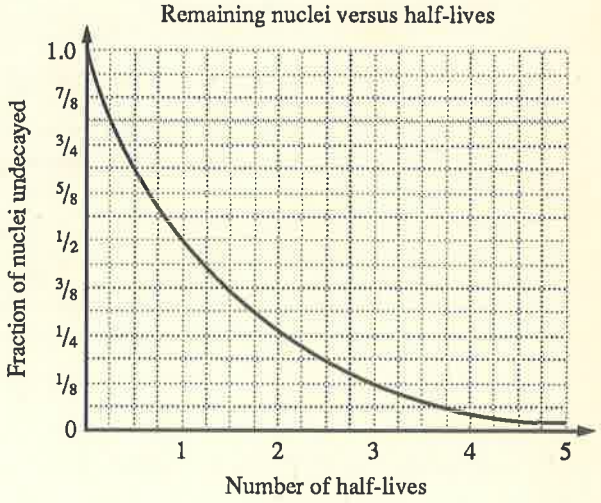
9. A sample of 1.0 g of tritium, $^{3}_{1}\text{H}$, is produced. What will be the mass of tritium remaining after 24.6 years?



Practice Problems

TABLE 30–1

Half-Life of Selected Isotopes

Element	Isotope	Half-Life	Radiation Produced
hydrogen	$^{3}_{1}H$	12.3 years	β
carbon	$^{14}_{6}C$	5730 years	β
iodine	$^{131}_{53}I$	80.7 days	β, γ
lead	$^{212}_{82}Pb$	10.6 hours	β, γ
polonium	$^{194}_{94}Po$	0.7 second	α
polonium	$^{210}_{84}Po$	138 days	α
uranium	$^{227}_{92}U$	1.1 minutes	α
uranium	$^{235}_{92}U$	7.1×10^{8} years	α, γ
uranium	$^{238}_{92}U$	4.51×10^{9} years	α, γ
plutonium	$^{236}_{94}Pu$	2.85 years	α, γ
plutonium	$^{242}_{94}Pu$	3.79×10^{5} years	α

24.6 years = 2(12.3 years) which is 2 half–lives. Since $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$ there will be

$(1.0\ g)\left[\frac{1}{4}\right] = 0.25\ g$ remaining

10. The isotope $^{238}_{93}Np$ has a half–life of 2.0 days. If 4.0 g are produced on Monday, what will be the mass of the neptunium remaining on Tuesday of the next week?

Amount remaining = (original amount)$\left[\frac{1}{2}\right]^{N}$

where N is the number of half–lives elapsed. Since N = 8 days/2.0 days = 4, Amount remaining = $(4.0\ g)\left[\frac{1}{2}\right]^{4} = 0.25\ g$

11. A sample of $^{210}_{84}Po$ is purchased for a physics class on September 1. Its activity is 2×10^{6} decays per second. The sample is used in an experiment on June 1. What activity can be expected?

The half–life of $^{210}_{84}Po$ is 138 days.

There are 273 days or about 2 half–lives between September 1 and June 1.
So the activity is

$$= \left[2 \times 10^{6}\ \frac{\text{decays}}{\text{s}}\right]\left[\frac{1}{2}\right]\left[\frac{1}{2}\right] = 5 \times 10^{5}\ \frac{\text{decays}}{\text{s}}$$

Practice Problems

12. Tritium, $^{3}_{1}H$, was once used in some watches to produce a fluorescent glow so the watch could be read in the dark. If the brightness of the glow is proportional to the activity of the tritium, what would be the brightness of the watch, in comparison to its original brightness, when the watch is six years old?

From Table 30–1, 6 years is approximately 0.5 half–life for tritium. Since Figure 30–4 indicates that approximately $\frac{11}{16}$ of the original nuclei remain after 0.5 half–life, the brightness will be about $\frac{11}{16}$ of the original.

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13. The mass of a proton is 1.67×10^{-27} kg.

a. Find the energy equivalent of the proton's mass in joules.

$E = mc^2$
$= (1.67 \times 10^{-27}\ kg)(3.00 \times 10^{8}\ m/s)^2$
$= 1.50 \times 10^{-10} J$

b. Convert this value to eV.

$$E = \frac{1.50 \times 10^{-10} J}{1.60 \times 10^{-19} J/eV}$$
$= 9.38 \times 10^{8}$ eV
$= 938$ MeV

c. Find the smallest total γ ray energy that could result in a proton–antiproton pair.

The pair will be (2)(938 MeV) = 1.88 GeV

Chapter Review Problems

pages 636–637

1. An atom of an isotope of magnesium has an atomic mass of about 24 u. The atomic number of magnesium is 12. How many neutrons are in the nucleus of this atom?

12 neutrons $^{24}_{12}Mg$

2. An atom of an isotope of nitrogen has an atomic mass of about 15 u. The atomic number of nitrogen is 7. How many neutrons are in the nucleus of this isotope?

   8 neutrons $^{15}_{7}N$

3. List the number of neutrons in an atom of each of these isotopes.

   a. $^{112}_{48}Cd$ 112 − 48 = 64

   b. $^{209}_{83}Bi$ 209 − 83 = 126

   c. $^{208}_{83}Bi$ 208 − 83 = 125

   d. $^{80}_{35}Br$ 80 − 35 = 45

   e. $^{1}_{1}H$ 1 − 1 = 0

   f. $^{40}_{18}Ar$ 40 − 18 = 22

4. Find the symbol for the elements that are shown by the following symbols, where *X* replaces the symbol for the element.

   a. $^{18}_{9}X$ F

   b. $^{241}_{95}X$ Am

   c. $^{21}_{10}X$ Ne

   d. $^{7}_{3}X$ Li

5. A radioactive bismuth isotope, $^{214}_{83}Bi$, emits a β particle. Write the complete nuclear equation and show the element formed.

   $^{214}_{83}Bi \rightarrow {}^{214}_{84}Po + {}^{0}_{-1}e$

6. A radioactive polonium isotope, $^{210}_{84}Po$, emits an α particle. Write the complete nuclear equation and show the element formed.

   $^{210}_{84}Po \rightarrow {}^{206}_{82}Pb + {}^{4}_{2}He$

Chapter Review Problems

7. An unstable chronium isotope, $^{56}_{24}Cr$, emits a β particle. Write a complete equation and show the element formed.

   $^{56}_{24}Cr \rightarrow {}^{56}_{25}Mn + {}^{0}_{-1}e$

8. During a reaction, two deuterons, $^{2}_{1}H$, combine to from a helium isotope, $^{3}_{2}He$. What other particle is produced?

   $^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{2}He + {}^{1}_{0}n$

9. One the sun, the nuclei of four ordinary hydrogen atoms combine to form a helium isotope, $^{4}_{2}He$. What type of particle is missing from the following equation for this reaction?

   $4\,{}^{1}_{1}H \rightarrow {}^{4}_{2}He + 2?$

   $4\,{}^{1}_{1}H \rightarrow {}^{4}_{2}He + 2\,{}^{0}_{1}e$

10. Write a complete nuclear equation for the transmutation of a uranium isotope, $^{227}_{92}U$, into a thorium isotope, $^{223}_{90}Th$.

    $^{227}_{92}U \rightarrow {}^{223}_{90}Th + {}^{4}_{2}He$

11. $^{238}_{92}U$ decays by α emission and two successive β emissions back into uranium again. Show the three nuclear decay equations and predict the atomic mass number of the uranium formed.

    $^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He$

    $^{234}_{90}Th \rightarrow {}^{234}_{91}Pa + {}^{0}_{-1}e$

    $^{234}_{91}Pa \rightarrow {}^{234}_{92}U + {}^{0}_{-1}e$

    $A = 234$

12. In an accident in a research laboratory, a radioactive isotope with a half–life of three days is spilled. As a result, the radiation is eight times the maximum permissible amount. How long must workers wait before they can enter the room?

For the activity to fall $\frac{1}{8}$ its present amount you must wait three half–lives, or 9 days.

13. If the half–life of an isotope is two years, what fraction of the isotope remains after six years?

$$\left[\frac{1}{2}\right]^3 = \frac{1}{8}$$

14. The half–life of strontium–90 is 28 years. After 280 years, how would the intensity of a sample of strontium–90 compare to the original intensity of the sample?

280 years is 10 half–lives. $\left[\frac{1}{2}\right]^{10}$ is equal to 9.8×10^{-4} or approximately 0.098%.

15. A Geiger counter registers an initial reading of 3200 counts for a radioactive substance and 100 counts 30 hours later. What is the half–life of this substance?

3200 counts to 100 counts represents 5 half–lives.

$$\frac{30 \text{ h}}{5} = 6 \text{ h}$$

16. A 14–g sample of $^{14}_{6}C$ contains Avogadro's number, 6.02×10^{23}, nuclei. A 5.0–g sample of $^{14}_{6}C$ will have how many nondecayed nuclei after 11 460 years?

$$\frac{(6.02 \times 10^{23} \text{ nuclei})}{14 \text{ g}} = \frac{N}{5.0 \text{ g}}$$

$$N = \frac{(6.02 \times 10^{23} \text{ nuclei})(5 \text{ g})}{14 \text{ g}}$$

$$= 2.1 \times 10^{23} \text{ nuclei}$$

After 2 half–lives only $\frac{1}{4}$ of the nuclei are nondecayed.

$$\left[\frac{1}{4}\right](2.1 \times 10^{23} \text{ nuclei}) = 5.4 \times 10^{22} \text{ nuclei}$$

Chapter Review Problems

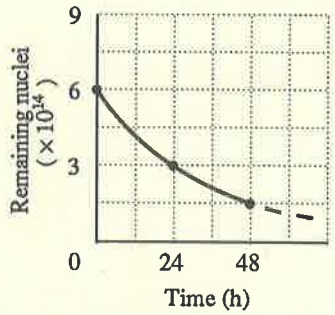
17. A 1.00 μg sample of radioactive material contains 6.0×10^{14} nuclei. After 48 hours 0.25 μg of the material remains.

a. What is the half–life of the material?

48 h is two half–lives, therefore 24 h is one half–life.

b. How could one determine the activity of the sample at 24 hours using this information?

Determine the slope (at 24 hours) of the line of a graph of remaining nuclei versus time.



The slope is
9×10^{12} nuclei/hour.

18. The synchrotron at FermiLab has a diameter of 2.0 km. Protons circling in it move at approximately the speed of light.

a. How long does it take a proton to complete one revolution?

$v = \frac{d}{t}$, so

$$t = \frac{d}{v} = \frac{\pi(2.0 \times 10^3 \text{ m})}{(3.0 \times 10^8 \text{ m/s})} = 2.1 \times 10^{-5} \text{ s}$$

b. The protons enter the ring at an energy of 8.0 GeV. They gain 2.5 MeV each revolution. How many revolutions must they travel before they reach 400 GeV energy?

$$\frac{(400 \times 10^9 \text{ eV}) - (8.0 \times 10^9 \text{ eV})}{2.5 \times 10^6 \text{ eV/revolution}}$$

$$= 1.6 \times 10^5 \text{ revolutions}$$

Chapter Review Problems

c. How long does it take the protons to be accelerated to 400 GeV?

$t = (1.6 \times 10^5 \text{ rev})(2.1 \times 10^{-5} \text{ s/rev})$
$= 3.4 \text{ s}$

d. How far do the protons travel during this acceleration?

$d = vt = (3.0 \times 10^8 \text{ m/s})(3.4 \text{ s})$
$= 1.0 \times 10^9 \text{ m}$, or about 1 million km

19. What would be the charge of a particle composed of three *u* quarks?

Each u quark has a charge of $+\frac{2}{3}$.

uuu $= 3\left[+\frac{2}{3}\right] = +2$ elementary charges

20. The charge of an antiquark is opposite that of a quark. A pion is composed of a *u* quark and an *anti–d* quark. What would be the charge of this pion?

$u + \bar{d} = +\frac{2}{3} + \left[-\left[-\frac{1}{3}\right]\right] = +1$ elementary charge

21. Find the charges of the following pions made of

a. *u* and *anti–u* quark pair.

$u + \bar{u} = +\frac{2}{3} + \left[-\left[+\frac{2}{3}\right]\right] = 0$ charge

b. *d* and *anti–u* quarks.

$d + \bar{u} = -\frac{1}{3} + \left[-\left[+\frac{2}{3}\right]\right] = -1$ charge

c. *d* and *anti–d* quarks.

$d + \bar{d} = -\frac{1}{3} + \left[-\left[-\frac{1}{3}\right]\right] = 0$ charge

Supplemental Problems

1. What particles, and how many of each, make up an atom of $^{109}_{47}\text{Ag}$?

47 electrons, 47 protons, 62 neutrons

Supplemental Problems

2. A calcium ion has 20 protons and 20 neutrons. Write its isotopic symbol.

$^{40}_{20}\text{Ca}$

3. What is the isotopic symbol of a zinc atom composed of 30 protons and 34 neutrons?

$^{64}_{30}\text{Zn}$

4. Write the complete nuclear equation for the alpha decay of $^{210}_{84}\text{Po}$.

$^{210}_{84}\text{Bi} \rightarrow {}^{4}_{2}\text{He} + {}^{206}_{82}\text{Pb}$

5. Write the complete nuclear equation for the beta decay of $^{14}_{6}\text{C}$.

$^{14}_{6}\text{C} \rightarrow {}^{0}_{-1}e + {}^{14}_{7}\text{N} + {}^{0}_{0}\bar{\upsilon}$

6. Complete the nuclear reaction:

$^{225}_{89}\text{Ac} \rightarrow {}^{4}_{2}\text{He} + \_\_\_\_\_$.

$^{225}_{89}\text{Ac} \rightarrow {}^{4}_{2}\text{He} + {}^{221}_{87}\text{Fr}$

7. Complete the nuclear reaction:

$^{227}_{88}\text{Ra} \rightarrow {}^{0}_{-1}e + \_\_\_\_\_ + \_\_\_\_\_$.

$^{227}_{88}\text{Ra} \rightarrow {}^{0}_{-1}e + {}^{227}_{89}\text{Ac} + {}^{0}_{0}\bar{\upsilon}$

8. Complete the nuclear reaction:

$^{65}_{29}\text{Cu} + {}^{1}_{0}n \rightarrow \_\_\_\_ \rightarrow {}^{1}_{1}p + \_\_\_\_$.

$^{65}_{29}\text{Cu} + {}^{1}_{0}n \rightarrow {}^{66}_{29}\text{Cu} \rightarrow {}^{1}_{1}p + {}^{65}_{28}\text{Ni}$

9. Complete the nuclear equation:

$^{235}_{92}\text{U} + {}^{1}_{0}n \rightarrow {}^{96}_{40}\text{Zr} + 3({}^{1}_{0}n) + \_\_\_\_$.

$^{235}_{92}\text{U} + {}^{1}_{0}n \rightarrow {}^{96}_{40}\text{Zr} + 3({}^{1}_{0}n) + {}^{137}_{52}\text{Te}$

10. An isotope has a half–life of 3.0 days. What percent of the original material will be left after

a. 6.0 days?

$\frac{6.0\text{ dy}}{3.0\text{ dy}} = 2$ half–lives, so $\left[\frac{1}{2}\right]^2 = \frac{1}{4}$, so 25% is left.

b. 9.0 days?

$\frac{9.0\text{ dy}}{3.0\text{ dy}} = 3$ half–lives, so $\left[\frac{1}{2}\right]^3 = \frac{1}{8}$, so 12.5% is left.

c. 12 days?

$\frac{12\text{ dy}}{3.0\text{ dy}} = 4$ half–lives, so $\left[\frac{1}{2}\right]^4 = \frac{1}{16}$, so 6.3% is left.

11. $^{211}_{86}$Rn has a half–life of 15 h. What fraction of a sample would be left after 60 h?

$\frac{60\text{ h}}{15\text{ h}} = 4$ half–lives, so $\left[\frac{1}{2}\right]^4 = \frac{1}{16}$ is left.

12. $^{209}_{84}$Po has a half–life of 103 years. How long would it take for a 100 g sample to decay so only 3.1 g of Po–209 was left?

$\frac{100\text{ g}}{3.1\text{ g}} = 32 = 2^5$, so 5 half–lives or 515 years.

13. The positron, $^{0}_{+1}e$, is the antiparticle to the electron and is the particle ejected from the nucleus in some nuclear reactions. Complete the nuclear reaction:
$^{17}_{9}\text{F} \rightarrow {}^{0}_{+1}e + \_\_\_\_ + \_\_\_\_$.

$^{17}_{9}\text{F} \rightarrow {}^{0}_{+1}e + {}^{17}_{8}\text{O} + {}^{0}_{0}\upsilon$

14. Complete the nuclear reaction:

$^{22}_{11}\text{Na} \rightarrow {}^{0}_{+1}e +$

$^{22}_{11}\text{Na} \rightarrow {}^{0}_{+1}e + {}^{22}_{10}\text{Ne} + {}^{0}_{0}\upsilon$

Supplemental Problems

15. Find the charge of a $\pi+$ meason made of a u and *anti–d* quark pair.

$u + \bar{d} = +\frac{2}{3} + -\left[-\frac{1}{3}\right] = +1$

16. Baryons are particles that are made of three quarks. Find the charge on each of the following baryons.

a. Neutron; d, d, u quark triplet.

$d + d + u = \left[-\frac{1}{3}\right] + \left[-\frac{1}{3}\right] + \left[\frac{2}{3}\right] = 0$

b. Antiproton; *anti–u*, *anti–u*, *anti–d* quark triplet.

$\bar{u} + \bar{u} + \bar{d} = -\left[\frac{2}{3}\right] + -\left[\frac{2}{3}\right] + -\left[-\frac{1}{3}\right] = -1$